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Physicochemical and structural composition of black rice (*Oryza sativa*) flour from Java, Indonesia

NURHIDAJAH[1,♥], DIODE YONATA[1], SUFIATI BINTANAH[2], BOBY PRANATA[1]

[1]Department of Food Technology, Faculty of Science and Agricultural Technology, University of Muhammadiyah Semarang. Jl. Kedungmundu Raya No. 18, Semarang 50271, Central Java, Indonesia. Tel./fax.: +62-812-2892-497, ♥email: nurhidajah@unimus.ac.id

[2]Department of Nutrition, Faculty of Nursing and Health Science, University of Muhammadiyah Semarang. Jl. Kedungmundu Raya No. 18, Semarang 50271, Central Java, Indonesia

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Abstract. *Nurhidajah, Yonata D, Bintanah S, Pranata B. 2024. Physicochemical and structural composition of black rice* (Oryza sativa*) flour from Java, Indonesia. Biodiversitas 25: 811-818.* Information regarding the characteristics of Indonesian black rice (*Oryza sativa*) flour from several varieties can provide a scientific base for developing its utilization. This study aimed to compare the physicochemical and structural composition of black rice varieties, namely Cempo Ireng, Melik, Sirampog, and Jeliteng from Java, Indonesia. Black rice was initially crushed to 100 mesh size. The flour's physicochemical and structural composition was then compared descriptively and the quantitative data was analyzed using the SPSS 22.0 software. As a result, significant differences were observed in starch content (68.45-71.08%), amylose content (13.99-18.49%), solubility (13.92-19.55%), swelling power (9.46-11.36%), water binding capacity (74.79-87.87%), and oil binding capacity (59.59-67.33%) of the four varieties of black rice flour. In addition, significant differences were also observed in the paste and thermal properties of various varieties. Morphological analysis shows that the flour structure has a similar shape, which is plate-shaped and contains many flakes. The relative crystallinity of Indonesian black rice flour ranges from 22.95% to 24.25%. This result reflects that all black rice flour particles have an A-type crystalline structure. All varieties of black rice flour have different physicochemical and structural compositions, except crystal structure that shows similarities (type A).

Keywords: Black rice, flour, Indonesian varieties, *Oryza sativa*, physicochemical, structure composition

INTRODUCTION

Rice (*Oryza sativa* L.) is the main cereal crop and the staple food of more than half of the world's population (Fukagawa and Ziska 2019). Compared to white rice varieties, pigmented rice varieties are a potential functional food source due to their bioactive compounds. Pigmented rice can be found in red, purple, brown, and black rice. The name refers to the color of the kernel, which is formed by the deposition of anthocyanin in different layers of the pericarp, seed coat, and aleurone (Sompong et al. 2011; Waewkum and Singthong 2021). Anthocyanins in pigmented rice have been widely used as compounds that provide health benefits (Deng et al. 2013; Tangsrianugul et al. 2019). The main anthocyanin in brown rice is found in the form of pro-anthocyanidin, although the main anthocyanin in purple rice and black rice is found in the form of cyanidin-3-glucoside (Ito et al. 2011; Abdel-Aal et al. 2016).

Apart from being consumed in the form of rice, black rice has now been developed into flour (Mazumdar et al. 2022; Sangma and Parameshwari 2023). Black rice flour has been used in various processing and applications in food, for example, as a main ingredient for wheat substitute dough to improve the rheological and structural properties of bread (Ma et al. 2019), main ingredient for making chiffon cous (Mau et al. 2017), substitute for wheat flour in making low-gluten muffins (Croitoru et al. 2018), as well as the main ingredient in making biscuits (Bolea et al. 2021). Black rice flour is known to contain relatively high amylose components (Ito and Lacerda 2019) of about 24.73-26.07% (Arifa et al. 2021). The presence of amylose in black rice has an important role in the physicochemical properties, structure, and morphology of flour. This will certainly affect the functional properties of the dough when applied to food products (Tangsrianugul et al. 2019).

More than 200 types of black rice varieties are found throughout the world. In Indonesia, recent research notes that as many as 24 local black rice varieties have been reported (Pratiwi and Purwestri 2017). Some of the various varieties of black rice have been massively cultivated, such as Cempo Ireng, Melik, Sirampog, and Jeliteng, especially in Java, Indonesia (Kristamtini et al. 2014, 2018; Arifa et al. 2021; Wadli and Hasdar 2021). Information regarding the physicochemical and structural composition of this variety is not yet available. According to Qadir and Wani (2023), each rice variety has a different structure. The amylose/amylopectin ratio, amylose-lipid complex, the presence of non-carbohydrate components such as lipids and proteins in the starch component, and variations in starch structure have been confirmed to influence the solubility properties, swelling ability, gel-forming ability, and the ability to form a good paste (Kang et al. 2011; Tangsrianugul et al. 2019). Flour is an important ingredient in the food industry. Flour with high swelling power, water binding capacity, and low solubility must provide functionally desired attributes in developing new food products (Singthong and Meesit 2017).

The chemical components, functional properties, and particle structure of rice flour have been confirmed to influence the overall quality of food products (Kraithong et al. 2018). Pigmented rice varieties play a significant role in developing functional food products with their functional components (Reddy et al. 2016). Therefore, characterizing Indonesian black rice flour's physicochemical and structural properties from various varieties is very important because of its extensive utilization, especially in the food industry. This research aimed to determine and compare the physicochemical and structural composition of black rice flour from four varieties, namely Cempo Ireng, Melik, Sirampog, and Jeliteng cultivated in Java, Indonesia.

MATERIALS AND METHODS

Research materials

Four black rice varieties were used in this study, namely Cempo Ireng, Melik, Sirampog, and Jeliteng (Figure 1) obtained from local farmers in Bantul and Sleman (Yogyakarta), Batang (Central Java), and Banyuwangi (East Java), Indonesia. Growing locations of black rice studied and their morphological characters are presented in Table 1. Dehulled rice grains were milled using a disc mill machine at 2800 rpm (Agrowindo, Indonesia) and passed through a 100-mesh sieve to obtain rice flour. The samples were kept at -18°C before analyses and all reagents were of analytical grade.

Procedures

The physicochemical composition studied in this research included starch content, amylose, solubility, swelling power, WBC, OBC, thermal properties using the Diffraction Scanning Calorimetry (DSC) instrument and paste properties using the Rapid Visco Analyzer (RVA) instrument, while the structural composition studied includes morphological analysis using a scanning electron microscopy (SEM) instrument and crystallinity analysis using an X-ray diffraction (X-RD) instrument.

Starch content

A modified version of the Nelson-Somogyi method was used to assess the starch content of black rice flour. The 2.5 g of the sample was dissolved in 250 mL of distilled water before 20 mL of 30% HCl was added. The solution was then heated using a condenser for 2.5 hours, cooled, and neutralized by adding 40% NaOH. The sample was then transferred into a 500 mL flask and filled with distilled water. The sample solution was then filtered using Whatman filter paper; 2 mL of the filtrate was pipetted and diluted into a 100 mL measuring flask. Later, the created solution underwent a lowering sugar analysis (i) About 50 mL of distilled water dissolved in 1 g of black rice flour. The solution was then made transparent by gradually adding Pb-acetate. Then, a dilution was created by doubling the volume of a 50 mL sample solution to 100 mL. Na-oxalate and half as much Pb-acetate were added to make a transparent solution. After filtering the solution with a Whatman cellulose filter paper, 50 mL was taken and diluted in a 100 mL volumetric flask. For solution (ii), a reduction of sugar analysis was also carried out. Before analyzing the reducing sugar, 1 mL of each of the solutions from (i) and (ii) was added to the test tube along with 1 mL of Nelson's reagent (Nelson A: B = 25:1). The test tube was then heated for 20 minutes in boiling water. Nelson A was created by mixing 500 mL of distilled water with 12.5 g of sodium bicarbonate, 12.5 g of potassium-sodium tartrate, 10 g of sodium bicarbonate, and 100 g of sodium sulfate. Nelson B was created by blending 50 mL of distilled water, 0.01 mL of H_2SO_4, and 7.5 g of copper hydroxide. After the combined solution had cooled to room temperature, 1 mL of arsenomolybdate was added. During homogenization, the residues were completely dissolved.

Figure 1. Black rice varieties used in the study. A. Cempo ireng, B. Melik, C. Sirampog, D. Jeliteng

Table 1. Characteristics of black rice growing locations

Parameters	Variety			
	Cempo Ireng	Melik	Sirampog	Jeliteng
Environmental conditions*				
Average temperature (°C)	27.63 ± 0.64	27.79 ± 0.43	28.81 ± 0.71	27.06 ± 0.58
Average annual humidity (%)	78.22 ± 6.27	76.32 ± 3.37	80.16 ± 1.06	80.02 ± 2.11
Light duration (hour/day)	8.58 ± 0.71	5.87 ± 0.45	10.01 ± 0.81	9.66 ± 0.58
Morphological characters				
Grain color	Black	Black	Black	Black
Grain length (mm)	8.26 ± 0.27	7.89 ± 0.13	7.46 ± 0.12	8.37 ± 0.27
Grain width (mm)	2.26 ± 0.18	2.30 ± 0.09	2.64 ± 0.25	2.31 ± 0.11
100-grain weight (g)	1.89 ± 0.05	2.15 ± 0.18	2.45 ± 0.05	1.14 ± 0.06

Note: *BPS-Statistics Indonesia (2023)

The mixture was then homogenized again after adding 7 mL of distilled water. Then, using a spectrophotometer (GENESYS 10S UV-Vis, Thermo Scientific, Waltham, MA, USA) set at 540 nm and a standard curve made of glucose (0, 20, 40, 60, 80, and 100 ppm), the concentration of reducing sugars was calculated. The starch content was calculated by using the following formulation (Setyaningsih et al. 2021):

Starch = 0.9 × (Reducing sugar (i) − Reducing sugar (ii))

Amylose content

Amylose content was measured using a modified colorimetric method. A 100 mg sample was put into a 100 mL measuring flask and added with 1 mL of 95% ethanol and 9 mL of 1 N NaOH solution. Then heated for 10 minutes in a boiling water bath, cooled, and diluted to the mark with distilled water. The 5 mL of the starch solution was put into a 100 mL measuring flask. The 1 mL of 1 N acetic acid and 2 mL of iodine solution were added and then diluted to the mark with distilled water. Then, it was shaken and left for 20 minutes, and the absorbance of the solution at a wavelength of 620 nm was determined. The amylose content is determined against a standard curve or conversion factor and expressed against dry weight (Qadir et al. 2021).

Solubility and swelling power

Determination of solubility and swelling power begins by preparing a flour suspension (1% w/v) and heating it in a water bath at 90°C for 30 minutes. The flour sample was centrifuged at 1500 rpm for 15 minutes, the supernatant was removed, and the sediment was weighed (W1). Aliquots of the supernatant were dried in an oven at 105°C until constant weight (W2) was obtained. Swelling capacity (SP, g/g) and solubility (S, %) are calculated using the formula described by Deng et al. (2020) as follows:

Swelling power (g/g) = W1 / sample weight x (100% - S)

Solubility (%) = W2 / sample weight x 100%

Water and oil binding capacity

Samples were prepared by dissolving 2.5 g of black rice flour in 20 mL of distilled water, vortexing for 30 minutes, and centrifuging 3000 g for 10 minutes. The supernatant was separated from the precipitated wet sample, then the wet sample was drained for 10 minutes and then weighed. The water binding capacity (WBC) is measured as grams of water bound by one gram of dry sample. The same procedure measures the oil binding capacity, although distillate water is replaced with 15 mL of corn oil. Oil binding capacity (OBC) is measured as grams of oil bound by one gram of dry sample (Chiranthika et al. 2022).

Thermal properties

Thermal properties of black rice flour were analyzed by a differential scanning calorimeter DSC-60Plus (Shimadzu, Japan) and TA-60WS collection monitor software. The 2 mg of starch was used and put in a pan for sample preparation. Distilled water was added to 10 µL, and starch samples were sealed for one hour. Sample pans were heated at 30-130°C with a rate of 10°C /min. Changes in enthalpy (ΔH) and transition temperature, including onset temperature (To), peak temperature (Tp), and conclusion temperature (Tc) were observed (Xiong et al. 2023).

Pasting properties

The Rapid Visco Analyzer instrument (RVA-4500, Perten Instrument, Australia) equipped with Thermocline for Windows 3 software was used to analyze the pasting properties of black rice flour. The sample was prepared as much as 3.5 g (14% moisture basis) into a container, and 25 g of distilled water was added. The stirring speed was 960 rpm for 20 seconds and 160 rpm for 50 seconds. The flour solution was then heated at 50°C to 95°C with a heat rate of 5.2°C/minute. The starch was held at 95°C for 5 minutes, cooled to 50°C at a rate of 5.2°C /min, and held at 50°C for 2 minutes. Pasting temperature, pasting time, peak viscosity, trough viscosity, breakdown viscosity, final viscosity, and setback viscosity were observed (Yonata et al. 2023).

Morphological structure

Black rice flour morphological properties were analyzed using scanning electron microscopy (SEM) (JEOL JSM-6510LA, Jeol Ltd., Japan) and auto coater JEOL JEC-3000FC. The flour sample was placed in a stub specimen, coated with carbon tape, and coated with gold. The gold coating procedure carried out put a sample in an auto coater with 3.2 Pa for 120 seconds. Potential accelerating was used to measure morphology properties at 10 kV. The images were captured at a magnification of 500x (Yonata et al. 2023).

Crystalline structure

The crystalline structure of black rice was analyzed using an XRD-6000 instrument (Shimadzu, Japan). The sample was scanned with a diffraction angle of 5 to 50 2θ. XRD was operated at 40 kV and 30 mA with a scanning speed of 4°/min (Farooq et al. 2021).

Data analysis

Quantitative data (starch, amylose, solubility, swelling power, WBC, OBC, relative crystallinity, thermal properties profile, and paste properties profile) were analyzed using the one-way analysis of variance (ANOVA) test method. It was continued with the Least Significance Difference (LSD) post hoc test to determine the significant difference between treatments with a significance level of $p<0.05$. Statistical analysis was performed using SPSS 22.0 software.

RESULTS AND DISCUSSION

Physicochemical composition

Starch and amylose contents

Black rice flour obtained from four varieties has a starch content ranging from 68.45 to 71.08%. Based on the ANOVA test, there are significant differences between varieties. The Sirampog variety contains significantly higher starch than other varieties (Table 2). A starch content that is barely different from black rice from West Java (69.78-72.75%) reported by Arifa et al. (2021), that is Cianjur (72.75%), Cempo Ireng (71.04%), Galur (71.36%), and Gadog (69.78%). The amylose content of black rice flour Sirampog variety (18.49%) was significantly higher than Cempo Ireng (15.73%), Jeliteng (15.24%), and Melik (13.99%) (Table 2). Amylose is a basic component of starch besides amylopectin. Differences in starch and amylose content in each variety can be influenced by climatic conditions and the soil where it is grown (Kong et al. 2015). Ideal growth conditions have been confirmed to positively correlate with plants' starch and amylose content (A'yuni et al. 2021). According to Purwanto et al. (2018), black rice burgeon in the highlands has sufficient light duration, ideal environmental temperature (26-31°C), and high humidity (>70%). Different types of soil result in differences in growth because each type of soil has different nutritional content. This affects the plant's ability to synthesize starch. The type of soil that produces the highest levels of starch and amylose is sandy loam (Wang and Zhan 2008). Sirampog variety black rice flour has a lower relative crystallinity (22.95%). The amylose component gets more easily retrograded after processing that involves heating. The condition explains that black rice flour of the Sirampog variety can be used for making noodles (Ahmed et al. 2016).

Solubility and swelling power

Solubility is the ability of a solid to dissolve or disperse in an aqueous solution and is related to the presence of dissolved molecules, such as amylose. The solubility of black rice flour was significantly different (p<0,05) (Table 2). The results showed that the solubility of Jeliteng (13.92%) and Cempo Ireng (14.01%) was significantly lower than Melik (14.64%) and Sirampog (19.55%). Kong et al. (2015) reported that rice starch with high amylose showed high solubility in water. This is possible because the amylose in black rice flour leaches more during heating. The results obtained in this research are in line with this theory, namely that rice with the highest amylose content (Sirampog) has the highest solubility value compared to other varieties. Swelling power (SP) is a material's ability to associate with water through hydrogen bonds under certain conditions. Temperature and water availability greatly influence SP (Akarsha et al. 2022). The SP of black rice flour is quite varied, ranging from 9.46% to 11.73% and statistically significantly different (Table 2). In this study, Cempo Ireng and Sirampog black rice flour had the highest SP, also containing more amylose. In contrast to the theory that swelling is a characteristic of amylopectin (crystalline area), this is due to weak intra and intermolecular coherence in starch (Shao et al. 2020). Besides amylose, the SP is also influenced by the structure of rice flour granules (Farooq et al. 2021). It was possible because there are plenty of long branch chains of amylopectin. This condition can increase the crystal structure's stability and suppress starch granules' swelling (Tangsrianugul et al. 2019).

WBC and OBC

The water binding capacity (WBC) and oil binding capacity (OBC) of black rice flour were 74.79-87.87% and 59.59-67.33% respectively (Table 2). Amylose and amylopectin ratio influence WBC. The more amylopectin component can increase WBC resulting from the negative charge of the phosphate group (Wang et al. 2016). In contrast, the lowest WBC (74.79%) was found in the Sirampog variety (p<0.05), which was due to the high amylose content compared to other varieties. High amylose levels allow for amylose-lipid/amylose-protein complexes, which reduce polar molecules that can disrupt WBC (Falade and Christopher 2015). Protein and carbohydrate components also influence WBC in black rice flour. It is possible because they absorb water and increase food consistency (Devisetti et al. 2014). There was a significant difference in OBC values (p<0.05) between varieties. OBC in black rice flour is influenced mainly by hydrophobic side chains associated with non-polar oil components. OBC is one of the functional properties of flour. Its existence is related to the physical trapping of oil through capillary action (Qadir and Wani 2023).

Thermal properties

The thermal properties of four varieties of black rice flour using differential scanning discalorimetry (DSC) are presented in Table 3. There are significant differences in gelatinization enthalpy ΔH (J/g) for all varieties (p<0.05). The lowest ΔH value was in the Sirampog variety, because it had the lowest relative crystallinity compared to other varieties. This is because the level of crystallinity drives the DSC parameter values (Kraithong et al. 2018).

Table 2. Physicochemical composition of black rice flour

Parameter	Variety			
	Cempo Ireng	**Melik**	**Sirampog**	**Jeliteng**
Starch (%)	69.16 ± 0.72^{ab}	68.45 ± 0.06^{a}	71.08 ± 0.17^{c}	69.68 ± 0.03^{b}
Amylose (%)	15.73 ± 0.51^{b}	13.99 ± 0.25^{a}	18.49 ± 0.45^{c}	15.24 ± 0.71^{b}
Solubility (%)	14.01 ± 0.36^{a}	14.64 ± 0.69^{a}	19.55 ± 0.44^{b}	13.92 ± 0.34^{a}
Swelling power (%)	11.73 ± 0.39^{c}	9.46 ± 0.18^{a}	11.36 ± 0.34^{c}	9.93 ± 0.70^{b}
WBC (%)	84.93 ± 1.11^{b}	87.87 ± 0.53^{c}	74.79 ± 0.47^{a}	75.91 ± 2.53^{a}
OBC (%)	67.33 ± 0.37^{b}	61.59 ± 0.70^{a}	59.59 ± 1.19^{a}	67.03 ± 1.62^{b}

Note: Data are means ± standard deviations. Values in the same row followed by the same superscript are not significantly different (p<0.05)

Table 3. Thermal properties of black rice flour

Parameters	Variety			
	Cempo Ireng	**Melik**	**Sirampog**	**Jeliteng**
To (ºC)	66.21 ± 0.12^{b}	65.08 ± 0.48^{a}	66.17 ± 0.36^{b}	66.82 ± 0.07^{c}
Tp (ºC)	71.03 ± 0.61^{b}	70.51 ± 0.09^{a}	70.37 ± 0.22^{a}	73.09 ± 0.41^{c}
Tc (ºC)	74.43 ± 0.04^{c}	73.96 ± 0.75^{b}	72.62 ± 0.28^{a}	76.25 ± 0.18^{d}
ΔH (J/g)	7.43 ± 0.02^{d}	6.59 ± 0.16^{b}	6.19 ± 0.19^{a}	6.86 ± 0.51^{c}

Note: Data are means ± standard deviations. Values in the same row followed by the same superscript are not significantly different (p<0.05).

The onset temperature (To) of Jeliteng is the highest, as are the peak temperature (Tp) and conclusion temperature (Tc). Thus, the energy required for the gelatinization of Jeliteng is higher than that required by Cempo ireng, Melik, and Sirampog (*p*<0.05). This result contradicts that reported by Tangsrianugul et al. (2019). In this study, the presence of amylose increased the gelatinization temperature. It was possible because long-chain amylopectin increases the double helix's stability, increasing the gelatinization temperature. Enthalpy indicates the energy to destroy starch in a double helix sequence (Sun et al. 2020). Plenty of energy is used to cook the flour until it gelatinizes; the amylose-lipid complex in black rice flour increases the temperature used in the gelatinization process. In this research, black rice flour with a high amylose content tends to require a high gelatinization temperature, which is reflected in the To value of the flour. These results align with Waewkum and Singthong (2021), who reported that amylose content was positively correlated with To, Tp, and Tc pigmented brown rice flour from Thailand. According to Pradipta et al. (2020), the thermal properties of pigmented rice are affected by amylose, amylopectin, lipid, and protein contents.

Pasting properties

Pasting properties are an important indicator in determining the application of flour and starch (Aidoo et al. 2022). In this study, the highest peak viscosity (3273.00 cP) was observed in Melik (*p*<0,05) (Table 4). It suggests that the starch granule has a strong hydrogen bonding capacity to bind water (Otegbayo et al. 2013). Furthermore, Cempo ireng presents the highest breakdown viscosity (1804.00 cP) (*p*<0,05). Besides that, Sirampog variety showed the highest pasting temperature (80.01ºC), final viscosity (4350.00 cP), and setback viscosity (3055.00 cP) (*p*<0,05) (Table 4). Rice flour compositions affect the differences in pasting properties values (Oko and Ugwu 2011). It is closely related to the amylose content in flour. High amylose flour requires higher temperatures for gelatinization (Kang et al. 2011). Higher fat and protein content is also an influence. Fats and proteins can form complexes with the amylose component, which causes the pasting temperature to increase. High amylose flour will show swelling, decreasing the peak viscosity (Waewkum and Singthong 2021). Flour with high final viscosity and setback viscosity tends to retrograde easily, so it has great potential for producing resistant starch. Based on its application, High peak viscosity flour is appropriately used in high viscosity and soft textured foods, while high setback flour is appropriately applied to stick rice noodles, fried snacks, and extruded products (Ahmed et al. 2015).

Structure composition of black rice flour

Morphological structure

Scanning electron micrographs (SEM) of black rice flour from four varieties are shown in Figure 2. All black rice flour shows the same grain shape, which is irregular with lots of flakes. These results align with the report of Kang et al. (2011). According to Reddy et al. (2017), pigmented rice flour grains are surrounded by non-starch components, such as proteins and fat. It is what causes many flakes around the particles. Variations in grain morphology may be due to rice's biological and physiological origins (Otegbayo et al. 2013). It refers to the amylose-amylopectin composition. Amylose and amylopectin play an important role in controlling the size and shape of granules (Kang et al. 2011).

Crystalline structure

X-ray diffractogram (X-RD) was used to verify the main peak and calculate each black rice flour's relative degree of crystallinity (%) which was described by Cheetham and Tao (1998). All black rice flours had clear A-type diffraction patterns with diffraction peaks at 15°, 17°, 18° and 23° (*2 theta*) (Table 5). Similar results have been reported for South Korean black rice (Kang et al. 2011) which black rice varieties Hwayoungbyeo, Dragon eyeball 100, Heukjinjubyeo, Heukgwangbyeo, Heuknambyeo, and Josaengheukchal. Black rice flour of the Sirampog variety contains the lowest relative crystallinity (22.95%), while the highest is the Melik variety (24.25%) (*p*<0,05) (Table 5). The presence of crystalline regions generally increases the grain size morphology of the particles due to branched-chain amylopectin (Kraithong et al. 2018). Thus, it could be said that in this study, black rice flour with low relative crystallinity contains more amylose.

Table 4. Pasting properties of black rice flour

Parameters	Variety			
	Cempo Ireng	Melik	Sirampog	Jeliteng
PT (ºC)	77.62 ± 0.27^c	73.69 ± 0.15^a	80.01 ± 0.12^d	77.12 ± 0.15^b
PV (cP)	3160.67 ± 57.18^c	3273.00 ± 49.00^d	2739.33 ± 42.78^a	3143.67 ± 74.10^b
BV (cP)	1804.00 ± 94.02^d	1797.22 ± 27.10^c	1450.33 ± 66.98^a	1764.33 ± 93.04^b
FV (cP)	4207.00 ± 25.06^c	4039.33 ± 43.43^a	4350.00 ± 85.81^d	4148.00 ± 46.16^b
SV (cP)	2850.33 ± 50.62^c	2563.67 ± 92.41^a	3055.00 ± 42.88^d	2768.67 ± 50.14^b

Note: Data are means ± standard deviations. Values in the same row followed by the same superscript are not significantly different ($p<0.05$).

Table 5. X-ray diffraction of black rice flour

Parameters	2θ (°)				Relative crystallinity (%)
	15°	17°	18°	23°	
Cempo Ireng	15.13	17.03	18.01	23.09	23.35 ± 0.64^b
Melik	15.15	17.09	18.04	23.04	24.25 ± 0.78^d
Sirampog	15.13	17.08	18.09	23.09	22.95 ± 0.92^a
Jeliteng	15.16	17.10	18.00	23.01	23.75 ± 0.21^c

Note: Data are means ± standard deviations. Values in the same column followed by the same superscript are not significantly different ($p<0.05$).

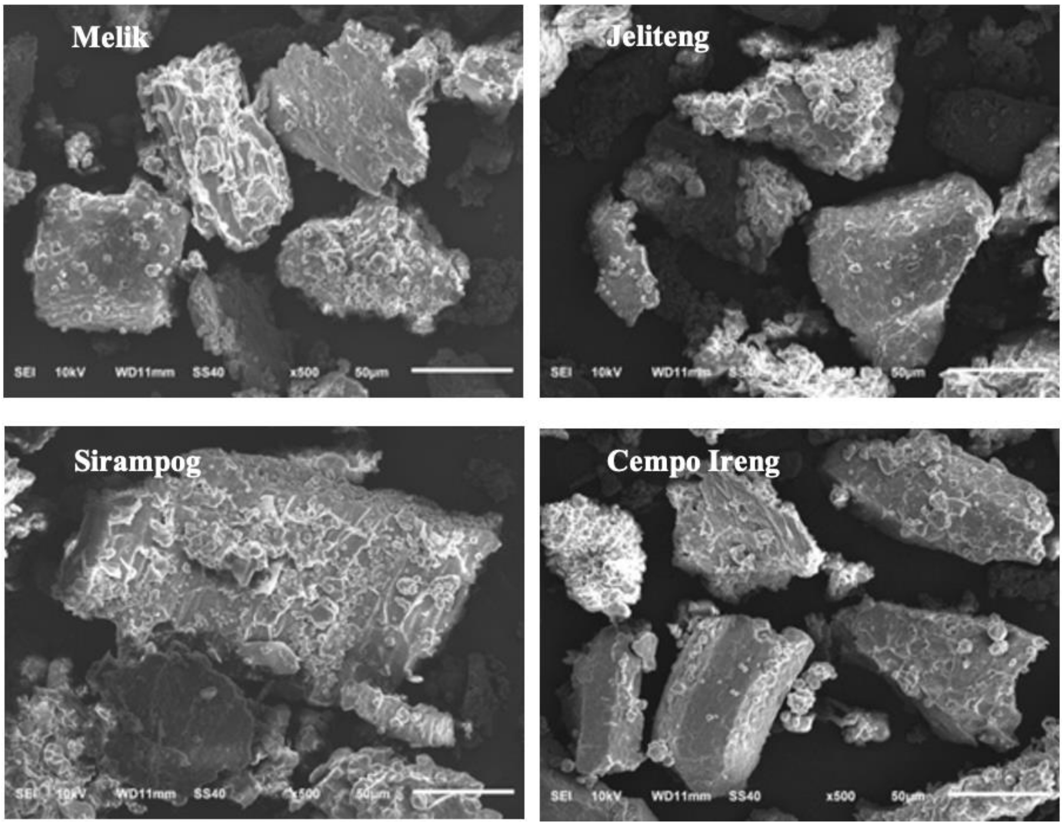

Figure 2. Scanning electron micrograph of black rice flour at 500x magnification

In conclusion, Cempo Ireng, Melik, Sirampog, and Jeliteng black rice varieties have different physicochemical and structural compositions between varieties. In general, black rice from Java, Indonesia has a high starch content with the amylose component differing significantly between black rice varieties. These differences also impact differences in structural processes, such as the relative crystallinity and structural morphology of black rice and the flour's thermal and pasta properties. All varieties of black rice flour show type A crystallinity structure. Sirampog variety black rice flour contains the highest levels of starch and amylose and the highest solubility among all varieties. The swelling power, WBC, and OBC values of Sirampog black rice flour were the lowest. It has a plate-shaped morphological structure with a few flakes with a relative crystallinity of 22.95%. In addition, this variety of black rice flour has a lower thermal profile with the highest pasting temperature and final and setback viscosity.

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